JOINT INSTITUTE FOR NUCLEAR RESEARCH
Meshcheryakov Laboratory of Information Technologies

FINAL REPORT ON THE INTEREST PROGRAMME
Introduction to Quantum Computing

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Spin Quantum Mechanics

- Particles exists in a superposition of states
- The state vector is given by Schrodinger equation:

$$i\hbar\frac{\partial}{\partial t}\psi(x,t) = -\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2}\psi(x,t) + V(x)\psi(x,t)$$

- The Stern-Gerlach experiment showed that a particle posses intrinsic angular momentum known as spin
- Electron spin is quantised $\uparrow$ or $\downarrow$
- All 2-level systems are equivalent to spin

Qubit frequency scan

Ipothesis: consider a qubit which has two states: a ground state $|0>$ and a excited state $|1>$.

Problem: which is the resonant frequency of the qubit?

Steps:

- run experiment on IBM Quantum Lab
- get data and plot with ROOT
- fit function:

$$\frac{A}{\pi}\cdot\frac{B}{(x-C)^2+B^2}+D$$

- get f0 (C)

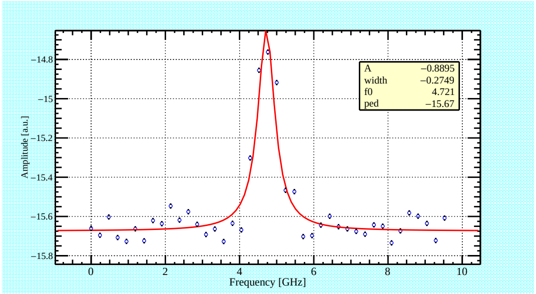

Figure 1: Pulse amplitude vs qubit frequency

The resonant frequency of the qubit is: 4.721 GHz.

Rabi qubit excitation

Ipothesis: Consider the same qubit with the two states. The transition from one state to another is made by a π rotation.
Problem: which is the amplitude of the π pulse?

Steps:

- run experiment on IBM Quantum Lab
- get data and plot with ROOT
- fit function:

$$A \cdot \cos\left(\frac{2\pi x}{B} - C\right) + D$$

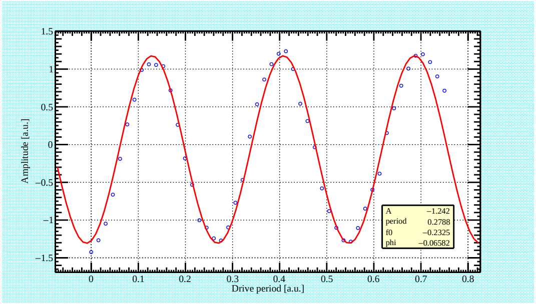

Figure 2: Pulse amplitude vs drive period

- get $A_\pi = C/2$

The amplitude of the π pulse is: 0.11625.

Discriminating 0 vs 1

Ipothesis: We consider a qubit in a superposition of $|0>$ and $|1>$ states and we apply a π pulse.
Problem: in which states the qubit is?

- run experiment on IBM Quantum Lab
- get data and plot with ROOT
- get mean values for each state:
  $|0>$: (-15.51, -5.72)
  $|1>$: (-13.13, -11.71)

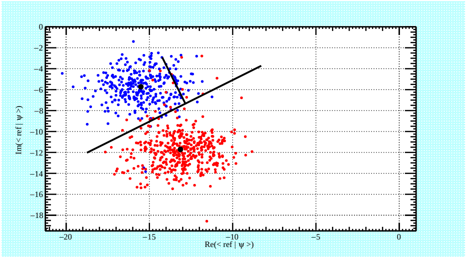

Figure 3: Current vs charge for $|0>$ (blue data) and $|1>$ (red data) qubit states

Discriminating 0 vs 1

- delimitation of the clusters:
    - separating line: $y_1 = 0.741x + 2.191$
    - perpendicular line: $y_2 = -3.186x + 48.29$
- project the points on $y_1 y_2$
- fit function: $A \cdot exp\frac{-(x-B)^2}{2 \cdot C^2}$
- fit parameters:
    - ground state: 14.1356; -3.219; 1.008
    - excited state: 18.1241; 1.242 ;1.016

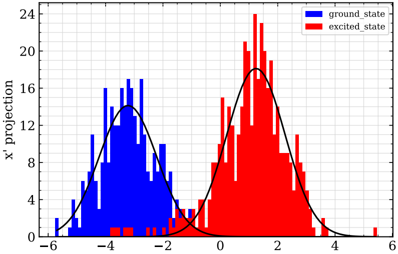

Figure 4: (x, y) projected on the perpendicular lines

The qubit is in state 0.

Qubit relaxation time T_1

Ipothesis: We consider a qubit in the state $|1>$. We define T_1 the qubit's relaxation time from state $|1>$ to state $|0>$.

Problem: which is the qubit relaxation time?

Steps:

- run experiment on IBM Quantum Lab
- get data and plot with ROOT
- fit function:

$$A \cdot \exp\left(\frac{-x}{B}\right) + C$$

- get $T_1 = B$

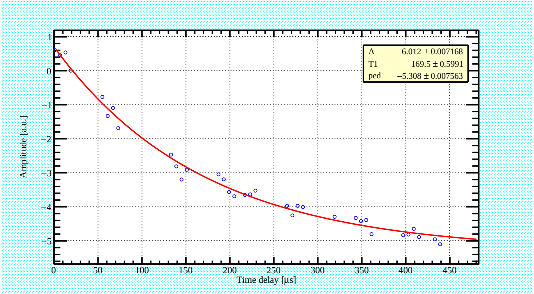

Figure 5: Pulse amplitude vs time delay

The qubit relaxation time is 169.5μs.

Ramsey experiment

Ipothesis: We consider a qubit with two states $|0>$ and $|1>$ and we apply two $\pi/2$ pulses with a time delay between them.

Problem: which is the qubit resonant frequency?

Steps:

- run experiment on IBM Quantum Lab
- get data and plot with ROOT
- fit function:

  $$A \cdot \cos\left(2\pi B \cdot x - B\right) + C$$

- get $f_0 = f_{0,est} + B[GHz]$

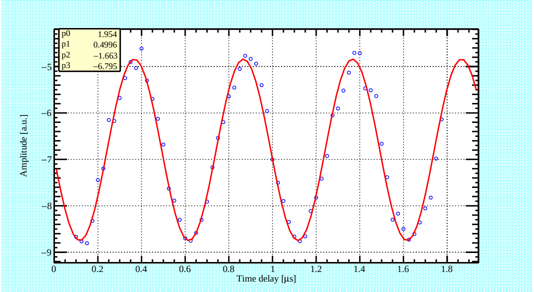

Figure 6: Pulse amplitude vs time delay

The qubit resonant frequency is 4.7214996 GHz.

Hanh Echo experiment

Ipothesis: We consider a qubit in a Ramsey experiment, but we add a π pulse between the two $\pi/2$ pulses.
Problem: which is the decay time T_2?

Steps:

- run experiment on IBM Quantum Lab
- get data and plot with ROOT
- fit function:

$$A \cdot \exp\left(\frac{-x}{B}\right) + C$$

- get $T_2 = B$

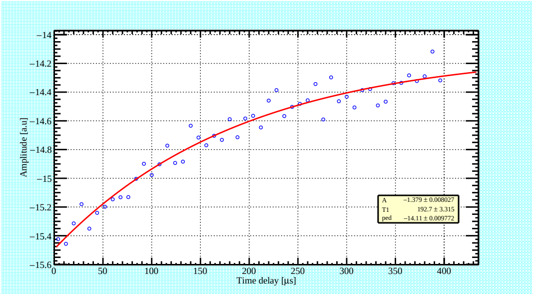

Figure 7:

The qubit relaxation time is 192.7μs.

Dynamical Decoupling

Ipothesis: We consider the Hanh Echo experiment, but we apply 6 π pulses between the two $pi/2$ pulses.
Problem: which is the decay time T_{2DD}?

Steps:

- run experiment on IBM Quantum Lab
- get data and plot with ROOT
- fit function:

$$A \cdot \exp\left(\frac{-x}{B}\right) + C$$

- get $T_2 = B$

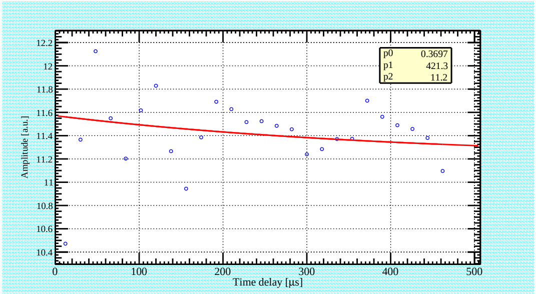

Figure 8:

The dynamical decoupling time is 421.3 μs.

QuLogic

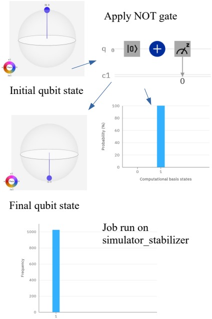

Figure 9: NOT gate

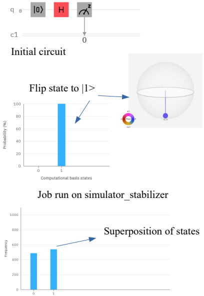

Figure 10: Hadamard gate

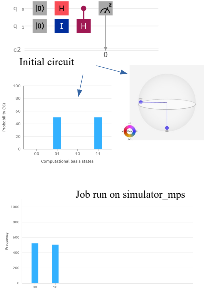

Figure 11: Entangled states

Quantum Algorithm

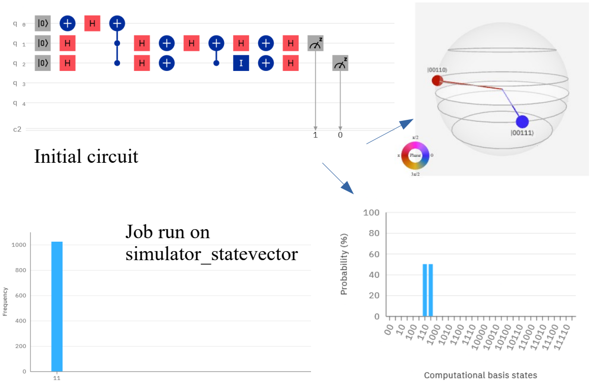

Figure 12: Grover algorithm

Conclusions

- The basics concepts of Quantum Mechanics are the pillars of the Quantum Computing theory, all 2-levels quantum systems being equivalent to electron spin.
- The quantum representation of the classical bit is defined as qubit. We studied the qubit characteristics with the IBM Quantum Lab.
- We could manipulate the qubit and change its states via Quantum Gates. In the IBM Quantum Composer we created superposition of states and implemented the Grover algorithm.
- I believe this course was a very smooth and educative introduction into the topic and I enjoyed to work with the IBM platform.